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# **Assessment of Electrical Resistivity Anomalies Caused by Fresh Water Discharge Across the Continental Shelf: Seeps off North Carolina**

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Shallow Water

## **LONG-TERM GOALS**

To determine the impact that fresh water discharge across the continental shelf has on the electrical resistivity structure of bottom sediments and, by so doing, to use electrical measurements to constrain the regional hydrology and the exchange of continentally derived groundwater with the ocean.

The strength and spatial distribution of resistivity anomalies caused by fresh water will be used to assess the likelihood of false target identification in mine counter measures, and the degree to which bottom conditions might be misclassified.

## **OBJECTIVES**

- Measuring and quantifying anomalous resistivity structures in a region of continental shelf known to be discharging fresh water into the ocean.

## **APPROACH**

The role of groundwater discharge on margin processes is one that is only beginning to be understood. Estimates of the amount of fresh water discharged from the continent through bedrock and into the ocean vary widely, and while some have suggested it is of a similar magnitude to riverine discharge, this remains a controversial issue. Most work to quantify the distribution and fluxes of fresh water across continental margins has been geochemical: there are few geophysical techniques that are sensitive to the presence of fresh pore water. However, electromagnetic techniques might respond to regions containing fresh water, as the electrical resistivity of the bulk sediment would be increased if the freshening were pervasive. We have seen off northern California regions of several hundred square meters which have extremely high electrical resistivities (for example, whereas normal sediments have resistivities of around 1 ohm-m near the seafloor, we saw values as high as several hundred ohm-m within 1-2m of the seafloor). Although we do not know at this time whether fresh water is responsible for these resistivities, we have carried out modeling based on observations of fresh water beneath the seafloor to show that this explanation is plausible (Hoefel and Evans, in press).

We used the same Canadian towed EM system that we have used in two successful ONR funded cruises, in three areas off North Carolina. The system, which is towed along bottom, provides more or less continuous resistivity-depth profiles along a tow line and so is ideal for providing spatial maps of resistivity variation, whether they are caused by changes in facies conditions or by the influence of groundwater. This is in contrast to other EM techniques which place a remote receiver on the seafloor and transmit to it with a towed source: local heterogeneity in resistivity structure at the length scale we are interested in will act as a source of noise in this kind of survey and will be hard to resolve.

The EM system measures the electrical resistivity of the seafloor which we convert to apparent porosity using empirical relationships and the assumption that the pore water has the same salinity as the near-bottom seawater. If this assumption is not valid, because the pore water is in fact fresher than seawater, then we will underpredict the porosity. In a survey off California, we predicted porosities of less than 15% in a few places close to shore. We know that these locations are immediately north of a shallow anticline system, and so one explanation for our observations has been that the pore water is fresh groundwater that is being channeled to the seafloor through faults associated with the anticline system. In the Californian case we have not been able to prove this model. In order to help determine that any observed anomalies in this survey are caused by fresh water and to place our measurements in the context of regional hydrology, we sampled fluids and took CTD measurements above areas of anomalous resistivity.

Chirp seismic profiles were also run in concert with the EM system. Seismic reflection profiling defines the geometry of sediment bedding, allowing any anomalous EM responses to be placed in a geological context.

## **WORK COMPLETED**

During a five day cruise on the R/V Cape Hatteras, we ran a series of EM and chirp seismic profiles off North Carolina. Our survey focused on areas in Onslow Bay and Long Bay offshore North Carolina. We focused on three areas, all of which were in water depths on the order of 15m. The seafloor off Carolina is typically referred to as "hard-bottom" with abundant limestone outcrops.

Although EM operations were limited by two losses and recoveries of the system, we acquired a substantial EM data set in all three areas. The data set is by far the most complex we have collected, reflecting the large variation in bottom conditions from sedimented seafloor to outcropping limestone.

## **RESULTS**

### **(1) Offshore Wrightsville Beach, N.C.**

This area was chosen as a result of discussions with Dr. W. Moore, Dr. S. Riggs, Dr. R. Thielier and Dr. W. Schwabb. High resolution side scan imagery, abundant coring and some seismic reflection profiling have been carried out across the region. A regional limestone aquifer continues offshore in this region and is buried beneath an Oligocene sequence. Carved into this sequence are a series of paleo fluvial-channels which in places appear to incise down to the top of the limestone aquifer. We have developed a numerical model of local hydrology and compared the results with our geophysical data from the area. We specifically test the hypothesis that these paleo-channels act as

vertical conduits allowing groundwater to leak from the aquifer to the seafloor. Numerical modeling suggests that groundwater within the limestone will be fresh to distances of about 1km offshore, and this result is consistent with our geophysical observations

## *(2) Long Bay Well Sites*

Recently observed temperature and geochemical signals from well sites in Long Bay, North Carolina have been interpreted as evidence for relatively high flux submarine groundwater discharge (SGD) a substantial distance offshore. We collected EM and chirp seismic data around this series of wells, and our data show evidence of submarine karst formation associated with this SGD zone. We suggest that groundwater transport to this location is most likely through a deep regional aquifer, and that this water percolates upward through a limestone unit within which we observe significant lateral contrasts in apparent porosity. These contrasts may have focused groundwater flow, creating a positive feedback between mixing, dissolution and discharge. Conditions favorable to the formation of similar locally punctuated sites of high flux SGD are likely to exist along the mid- to inner shelf of the southeastern U.S., where carbonate aquifers are prevalent.

## **IMPACT**

The loss of continental groundwater to the oceans is a potentially important area of research both from an oceanographic and from a societal viewpoint. Thus, the use of EM surveys to identify groundwater discharge will be of fundamental importance, not only to the Navy in its mine counter measures efforts, but also to a large geological and hydrological community seeking to understand the exchange of groundwater with the oceans. To date, there is a lack of geophysical constraint on this process, since few methods have direct sensitivity to the presence of fresh pore water. If our survey is successful, it will open up a new avenue of exploration.

## **RELATED PROJECTS**

I have been funded by NSF to develop a towed EM capability at WHOI, and work is almost complete on the construction of this system based on the design of that used in this survey. Additional support was provided by the Rhinehart Coastal Research Center at WHOI to carry out a series of land-based resistivity profiles along Wrightsville Beach in an effort to tie channel sequences seen offshore to onshore creek systems. Several trips to Wrightsville Beach have been completed and Em data onshore show evidence for saltwater intrusion into the main limestone aquifer.

## **PUBLICATIONS**

Evans, R.L., D. Lizarralde, Geophysical evidence for karst formation associated with offshore groundwater transport: an example from North Carolina, submitted to *G<sup>3</sup>*.

Mulligan, A., R.L. Evans and D. Lizarralde, The role of paleochannels in groundwater-seawater exchange. Submitted to *J. of Hydrology*.